AD-A161 557

UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION: Unclassified	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT: Approved for public release; Distribution unlimited.
2b. DECLASSIFICATION / DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S): N/A	5. MONITORING ORGANIZATION REPORT NUMBER(S): AFATL-TR-85-98
6a. NAME OF PERFORMING ORGANIZATION: Clusters and Warheads Branch — 6b. OFFICE SYMBOL (If applicable): AFATL/DLJW	7a. NAME OF MONITORING ORGANIZATION
6c. ADDRESS (City, State, and ZIP Code): AFATL/DLJW, Eglin AFB, FL 32542-5000	7b. ADDRESS (City, State, and ZIP Code)
8a. NAME OF FUNDING/SPONSORING ORGANIZATION — 8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS (City, State, and ZIP Code)	10. SOURCE OF FUNDING NUMBERS

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT ACCESSION NO.
63601F	670A	GG	69

11. TITLE (Include Security Classification)

AN EIGHT-INCH DIAMETER, HEAVILY CONFINED CARD GAP TEST

12. PERSONAL AUTHOR(S)

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13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
	FROM ____ TO ____		9

16. SUPPLEMENTARY NOTATION

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	Shock Sensitivty Testing; Gap Test
19	01		Explosive Sensitivity; Sympathetic Detonation
	04		Explosive Testing

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

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20. DISTRIBUTION/AVAILABILITY OF ABSTRACT: ☐ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION: Unclassified
22a. NAME OF RESPONSIBLE INDIVIDUAL: Joseph C. Foster, Jr.	22b. TELEPHONE (Include Area Code): (904)-882-2141 — 22c. OFFICE SYMBOL: AFATL/DLJW

DD FORM 1473, 84 MAR — 83 APR edition may be used until exhausted. All other editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE
UNCLASSIFIED

AN EIGHT-INCH DIAMETER, HEAVILY CONFINED CARD GAP TEST

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An instrumented card gap test which is useful for investigating the response of explosives to low pressure, long duration shock stimuli has been developed. The test was designed to screen for an explosive's (or propellant's) propensity to detonate or react violently as result of shock induced sympathetic detonation of large ordnance such as general purpose bombs. Both donor and acceptor are encased in an 8 in. outside diameter by 0.35-in. wall steel pipe. The donor is Composition B, one-diameter long, and point-initiated on axis. Acceptors are two diameters long. Typically, both donor and acceptor tubes are closed with 0.50-in. thick steel end plates. Plexiglass, of varying thickness, and steel end plates are used to control the shock amplitude transmitted into the acceptor. The acceptor is instrumented with piezoelectric time of arrival pins. The assembly rests on a vee-groove wood block which rests on a 1-in. thick armor plate; the armor plate serves as a fragment witness. Hydrocode calculations were performed to describe input pressure profile as a function of gap thickness and configuration. The calculations show that the end plates result in significantly longer pressure durations and lower peak pressures than other gap tests, and in a more realistic mock of the shock loading experienced in large ordnance sympathetic detonation experiments. Results presented includes data for tritonal, Composition B, TNT/WAX, and TNT/NQ/WAX. The range of pressures resulting in transition to detonation for different explosives is narrower for this test than that measured in experiments such as the NOL LSGT. The instrumentation used permits a determination of detonation velocity as well as distance required to run up to detonation as a function of input shock strength.

INTRODUCTION

The storage of large quantities of high explosives presents a unique engineering problem from the point of view of the safety engineer[3]. One aspect of understanding the potential hazard associated with explosive storage is the characterization of the shock sensitivity of the material of interest. In situations where large charges (100-1000 kg) are stored in near proximity, the conditions under which adjacent charges undergo sympathetic detonation might be significantly different than those determined from small scale experiments. The experimental techniques in this paper address this problem.

The scale of the experiment provides for characterization of explosive response to large amplitude long duration pressure pulses. A number of similar experimental techniques are used to measure the response of explosives and propellents to pressure pulses[1]. The technique presented in this paper is distinguished from previous techniques by the long duration pulse which is the result of the relatively large scale of the experiment.

Several investigators have addressed the relationship between amplitude and duration of the applied shock as it applies to determining shock sensitivity of explosives[2,3]. The present tech-

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nique, however, provides loads of duration 10 - 40 microseconds as opposed to 1 - 10 microseconds usually discussed.

In addition to the long duration nature of the shock structure used in the experiment, the wave structure is modified by impedance discontinuities between the donor charge and the acceptor charge. There has been no attempt to specifically tailor the wave shape using this approach but rather to simply model in the experiment the wave structure representative of the problem posed by two adjacent steel encased charges. This problem provides data which applies directly to the storage of large unitary weapons such as the Mark 80 series of conventional general purpose bombs.

An investigation of shock sensitivity seeks to determine the minimum input (a limiting shock strength) that will produce steady-state detonation in an explosive. Steady-state detonation can occur only when chemical energy released in reaction continually restores energy loss by the shock wave through dissipation into internal and kinetic energy loss to the media. If an initial shock strength is greater than the steady-state detonation strength, the energy supplied through chemical reaction is insufficient to maintain such strength and the wave decelerates to the steady-state or Chapman-Jouguet (CJ) detonation. On the other hand if the initial shock strength is less than that of the CJ wave, the chemical energy supplied may not be sufficient to accelerate the shock wave to steady-state detonation. A limiting initial shock strength does exist that although weaker than the CJ wave is still strong enough to be boosted into detonation by the energy of chemical reaction. This limiting shock strength is an important experimental point in the definition of an explosive's shock sensitivity.

A simple method for determining the shock sensitivity of an explosive is the Naval Ordanance Laboratory's (NOL) gap test. The NOL gap test consists of a 2-in. by 2-in. cylinder of pressed tetryl to supply an initial shock through a variable Lucite gap to a moderately confined acceptor charge (1.437-in. diameter by 5.5-in. length). "Go,no-go" is determined by a hole punched through a 3/8-in. thick mild steel witness plate on the end of the acceptor. By adding thickness to the Lucite cards, the shock can be attenuated and thus a limiting shock for detonation can be determined.

TEST TECHNIQUE

The shock sensitivity of an explosive relates directly to questions of safety in the handling, transporting and storing of munitions. The scale of munitions, however, is much greater than the scale of the NOL large scale gap test. A MK-82 bomb, for example, has a diameter of 10.75-in. and contains about 200 lbs of explosive. The NOL gap test with a scale of 1.4-in. diameter and less than 1/2 lb of explosive is inappropriate to study shock sensitivity in large munitions. A major difference is the time dependent signature of the pressure pulse transmitted in these two environments. In order to measure shock sensitivity as it applies to the safety of large munitions, an eight inch diameter, super large scale gap test was devised which models the pressure-time pulse transmission of a detonating MK-82 to its nearest neighbor in a storage configuration.

The set-up of the super gap test is shown in Figs. 1 and 2. The donor charge in this test is a 7.15-in. diameter by 8-in. long Composition-B cylinder confined by a 0.35-in. thick steel case around the charge and 0.5-in. steel plates on both ends. The donor charge is initiated with an RP-2 EBW detonator boosted with a 1-in. by 1-in. Composition A-5 pellet (Fig. 3). Polymethylmethacrylate (PMMA) cards are used to attenuate the input shock. These cards are disks 8-in. in diameter and either one or two inches thick and are stacked to various thicknesses behind the donor charge. The acceptor charge is 7.15-in. in diameter and 16-in. long and confined by a 0.35-in. thick steel case and two 0.5-in. steel end plates.

The 6-ft by 3-ft by 1-in. rolled homogeneous armor (RHA) witness plate is not placed on the end of the acceptor as in the NOL gap test but is placed parallel to the length of the charges at a 6.75-in. stand-off from the centerline. This stand-off is maintained by a slotted "two by four" assembly which holds the charges and PMMA cards in place on top of the witness plate. The wood also supplies protection to the witness plate to prevent casing fragments from penetrating the plate. Sand bags positioned around the test set-up further protects the witness plate and more importantly protects the surrounding area. Fragments, however, do mark the plate on angles not covered by the wood and sand bags. The position of the fragment markings can be used to determine a distance of run for the test as well as "go, no-go". Figure 4 and 5 show th typical fragment markings found on a witness plate.

During reaction, a portion of the acceptor casing along the length of the charge is accelerated into the two by four stand resulting in a soft catch of a large fragment--in reality a strip off the acceptor can (Fig. 6). This fragment also maps the history of detonation in the charge. Adiabatic shear in the

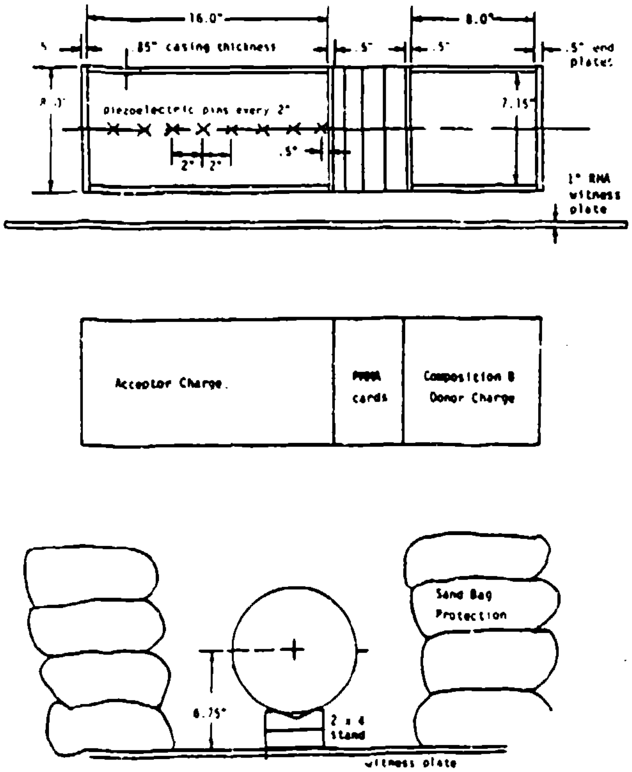

Fig. 1. Set-up of the Super Gap Test

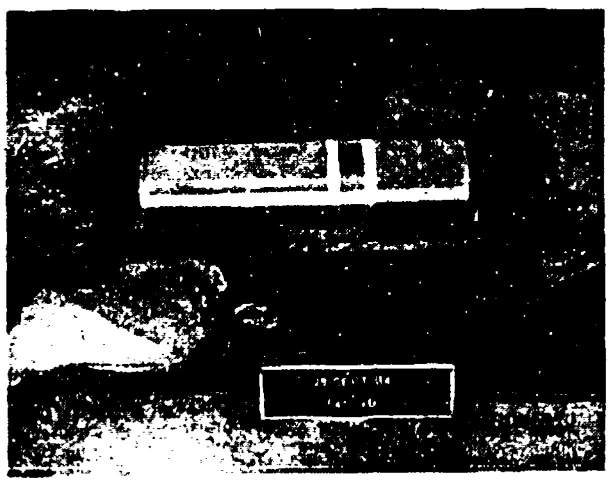

Fig. 2. Set-up of the Super Gap Test (2 inch PMMA gap)

Fig. 3. Set-up of the Super Gap Test with Booster

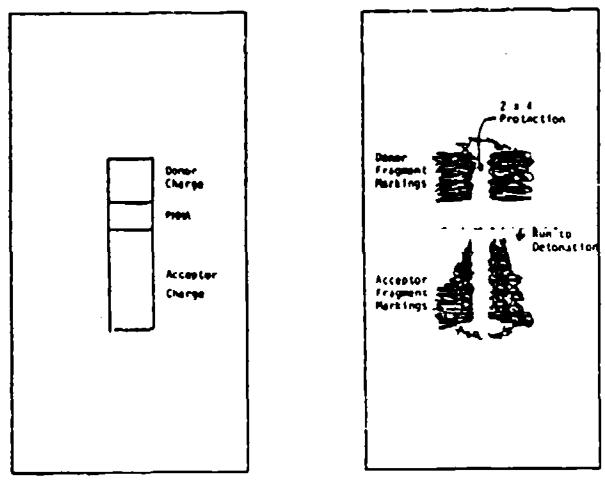

Fig. 4. Description of Witness Plate Results

casing is witnessed on the strip when detonation is reached. The markings on this fragment corresponds well with markings on the witness plate.

In order to further define the detonation velocity and run distance to detonation, piezoelectric pins (Dynasen Inc., CA-1136) are inserted through the acceptor casing into the explosive. These pins, 3/32-in. in diameter and 3-in. long, are inserted nominally 2-in. into the acceptor explosive with approximately 1/2-in. remaining outside the casing to which cables (Dynasen Inc., C-1146-2) are attached to carry the signals to recording instruments. The cables are multiplexed into a single cable by means of a circuit shown in Fig. 7 and this cable is attached to a HP5180 transient digital recorder. The response of the recorder being 20 MHz, signals can be resolved within 50 nanoseconds. As a piezoelectric pin is stressed, it pro-

Fig. 5. Typical Witness Plate Data

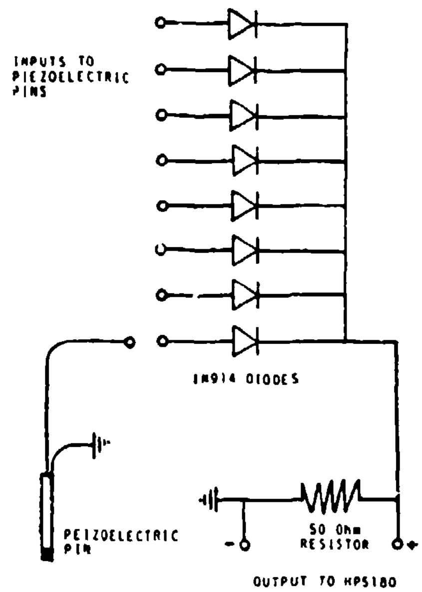

Fig. 7. Circuit for Multiplexing Piezoelectric Pin Response.

Fig. 6. Acceptor Case Fragment

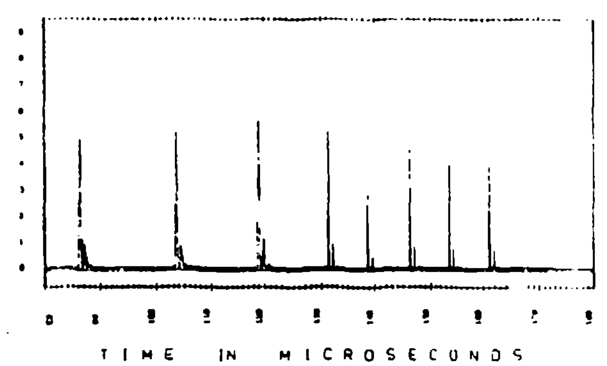

Fig. 8. Typical Output of Piezoel ctric Pins

duces an electrical charge. Thus a shock wave passing across a pin would produce a sharp peak (typically 150 ns rise time) from which time of arrival can be measured. The multiplexing puts all of the pin signals on one channel. Thus the time between signals is simply the time it takes for the shock wave to travel between pins. In the test set-up, the pins are spaced every 2-in. along the acceptor charge with the first pin being 1/2-in. from the forward explosive metal interface. Knowing distance and time of arrival for each pin, the average wave velocity across the 2-in. intervals can be monitored along the length of the acceptor. Figure 8 shows the out put of a typical channel of eight piezoelectric pins. The time of arrival of the shock wave along the acceptor is determined from this data.

The data from the pins can most effectively be plotted as velocity versus distance along the acceptor. In a detonating charge, sufficient data points may be obtained to calculate an accurate detonation velocity. Increasing thickness of PMMA corresponding to weaker input shock strength can be shown to result in increased run to detonation. Data from the witness plates and fragment strips confirm such measurements.

The advantage of the super gap test is its ability to characterize run distance to detonation and shock velocity along the acceptor length which can better define the phenomenon of "go, no-go" in the study of shock sensitivity and the correlation of the test to full scale munitions which can prove more applicable to current military utilization and the study of safe handling, transportation and storage of weapons.

Data is presented for a selection of well known explosives (Composition-B, Tritonal). Another area of interest is the formulation techniques which can be used to desensitize the response. Data is presented on formulations which were modified in an attempt to desensitize.

CALCULATIONS

The Hull hydrocode was employed to assist in analyzing the results of the super gap test. Hull is an Eulerian hydrocode which solves the conservation equations of mass, momentum, and energy. Hull has an extensive material library which allowed for easy modification of existing material properties to model explosives and PMMA. The JWL (Jones-Wilkens-Lee) equation of state was used for the detonation products and the Mie-Gruneisen equation of state for the steel, PMMA and unreacted explosive. Hull does not currently have the capability to shock initiate explosives so the objectives of the computer analysis were to determine peak pressure, positive pulse duration, and time of arrival of the peak pulse in the acceptor charge.

The following is a list of some of the important properties used in the Hull Material Model code for PMMA and one developmental explosive used in the study, ethylene diamine dinitrate, ammonium nitrate, and potassium nitrate (EAK):

MATERIAL	SOUND SPEED (cm/sec)	DENSITY (gm/cm3)	SLOPE (U_S/U_P)
EAK	2.657E5	1.61	1.796
PMMA	2.71E5	1.17	1.48

The data for EAK was taken from a report published by Los Almos. Due to a lack of time, no in-house experiments were specifically performed to check the above properties, however, since the peak arrival time calculated by Hull agreed fairly well (within 5%) of the recorded data for undetonated EAK, the material properties were not changed throughout the calculational series.

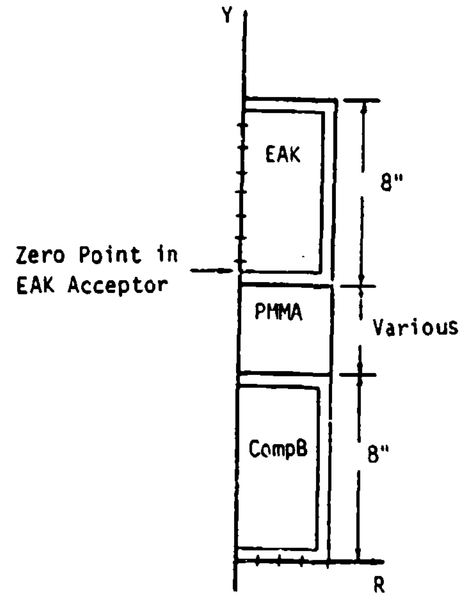

Fig. 9. Computational Model of Super Gap Test with EAK Acceptor

A represantative calculational model is shown in Fig. 9. The calculation was performed in 2D with cylindrical coordinates. The cell size was .2x.2 cm^2. Constant rezoning was employed to help track the wave front and ensure material interfaces were well preserved. Due to the simple model under consideration, a programmed burn with point initiation was used. Data collection stations were placed in the donor to ensure wave velocity and pressure were at the CJ point.

The results of the calculations are shown in Fig. 10. The graph depicts the pressure calculated one-half inch into the EAK acceptor on the centerline. A simple P=K/R equation was used to curve fit the points. (P=pressure, K=constant, R=thickness of PMMA). Naturally, due to the reflections at the interfaces, this model only grossly approximates the curve and is at best only valid for the range under consideration.

Figure 11 is a model of the NOL card gap test (a pentolite donor models the tetryl donor) which was calculated to check the veracity of the Hull results. Figure 12 is a curve taken from AMCP 706-180 which plots shock pressure as a function of gap thickness recorded from various NOL gap tests. The circles on the curve are the results of the HULL calculation of the same event. Some deviation occurs as the thickness of the lucite increases beyond 40mm but overall the comparison is very good.

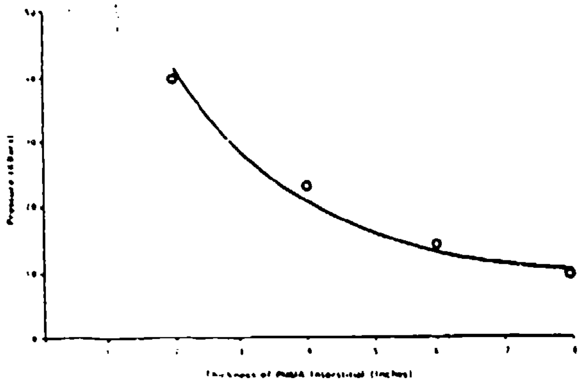

Fig. 10. Centerline Pressure Pulse of EAK Acceptor (1/2" into EAK)

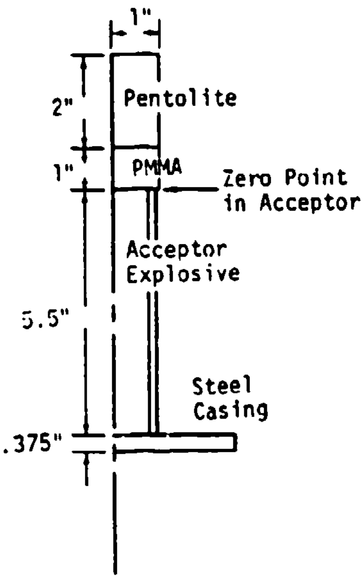

Fig. 11. Computational Model of NOL Gap Test

Calculations were performed to describe input pressure to the acceptor as a function of gap thickness (Fig. 13). These calculations were performed to enable clarification of the function of the endplates of the charges in the role as shock attenuators. As can be seen, without endplates the pressure pulse decays rapidly until approximately 4 inches of PMMA have been traversed, at which time an inflection point is reached and the decay is moderated. However, with endplates, the pressure decays much slower and if an inflection point exists, it occurs between zero and one inch. Also the positive pulse duration of the transmitted pulse is longer with endplates than without.

Calculations of transmitted impulse were also performed with and without

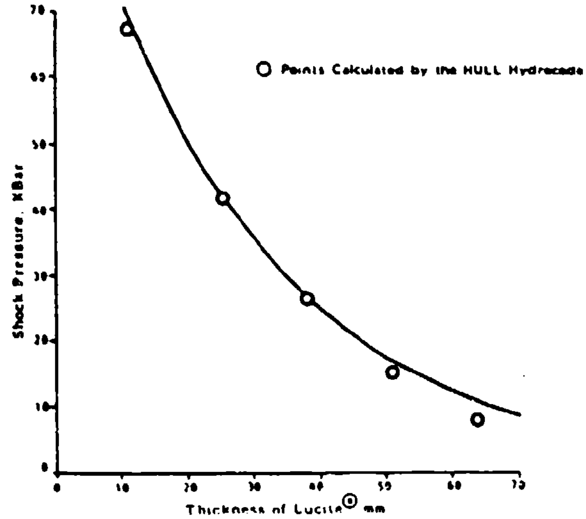

Fig. 12. Shock Wave Pressure at the End of the Lucite Gap in the NOL Gap Test

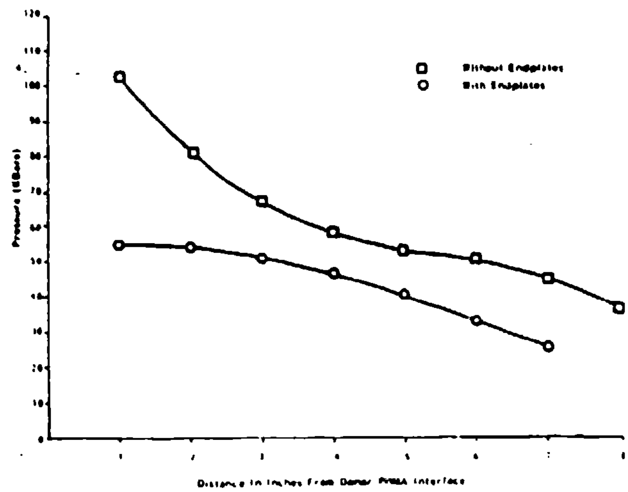

Fig. 13. Shock Wave Pressure at the End of the PMMA Gap in the Super Gap Test

endplates and the results plotted in Fig. 14. The graph depicts specific impulse plotted as a function of pressure. Note that the same impulse may be arrived at with two different peak pressures. This results from the attenuation ability of the endplates Since,

$$I = \int P dt$$

the conclusion to be drawn is that the positive pulse duration of the pressure spike is greater with endplates than without. This supports the P^2-t function which has been used for some time to approximate shock initiation criterion.

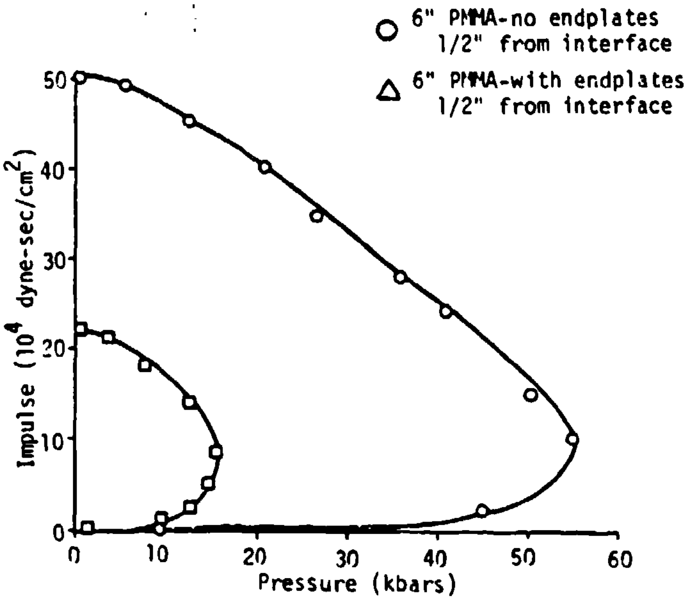

Fig. 14. Pressure vs Impulse for Acceptor Charges with and without Endplates

TEST RESULTS

To verify the utility of the super gap test, a series of baseline shots was accomplished with Composition-B acceptors. Figure 15 plots the time of arrival (TOA) of the shock waver pressure peak at various locations along the acceptor where piezoelectric pins are positioned. The first shot was set-up with a gap of 6-in. PMMA between the donor and acceptor charges, corresponding to a 14 kbar input shock to the acceptor charge from calculations. The linear slope of the TOA vs distance curve reveals that a stable detonation velocity is reached early in the charge. A plot of the slope of the curves ($\Delta x/\Delta t$) shown in Fig. 16 further defines the shock wave velocity in the acceptor. In the 6-in. PMMA gap test, the shock wave reaches detonation velocity within four inches of run. The witness plate for this shot confirmed the four inch run to detonation. An 8-in.PMMA gap is then shot to define a "no-go" point. The slower response time and the velocity decay of this shot defines no detonation of the acceptor which is again confirmed with data from the witness plate and fragments. A 7-in. PMMA gap also produces a "go" with a run of five inches to detonation. A 9-in. PMMA gap with the endplates of the charges removed gives a peak pressure comparable to the 7-in. gap but with a differing impulse according to calculations. The pin data reveals a rise to detonation of 2.5 inches and gives good data points to determine a

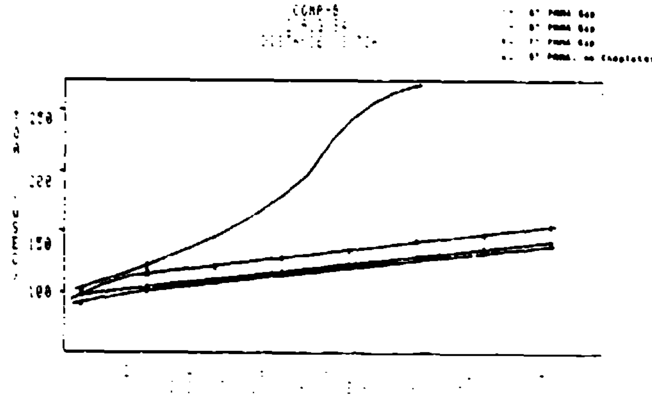

Fig. 15. Time of Arrival vs Distance along Acceptor for Composition-B

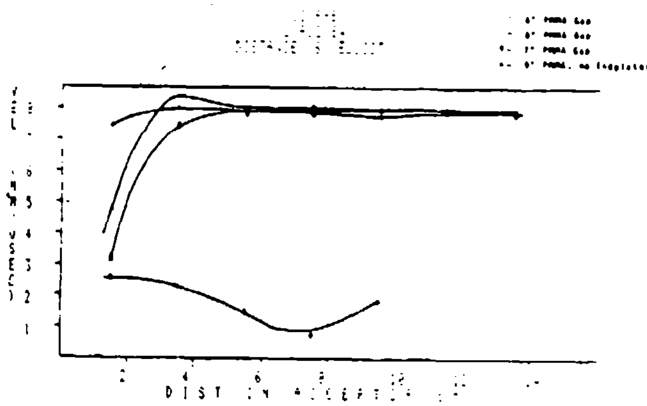

Fig. 16. Velocity vs Distance along Acceptor for Composition-B

value for detonation velocity. Eighteen points from the tests for detonating Comp-B are available to calculate a detonation velocity of 7.91 mm/us with a standard deviation of 0.17 mm/us.

Baseline tritonal acceptors were also shot in the super gap test configuration (Fig. 17). Because of hardware constraints, half-length (8 inch) acceptors were used in tests with 4-in. PMMA and 7-in. PMMA gaps. The 4-in. PMMA gap produced a "go" rising to 6.9 mm/us in 5.5 inches and the 7-in. PMMA gap resulted in a "no-go". A shot with a 5-in. gap reached detonation with a 9.5 inch run. An additional shot was accomplished at a 6-in. PMMA gap which although tending to rise to detonation still resulted in a "no-go". The detonation velocity for tritonal was measured at 6.85 mm/us $\pm$ 0.04 in these tests.

A series of shots of the super gap test with a TNT/5%-wax acceptor also

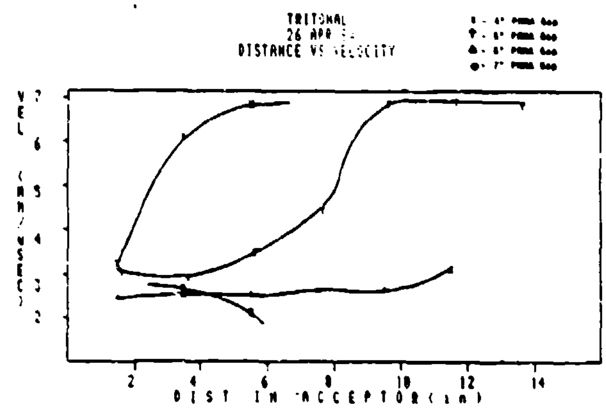

Fig. 17. Velocity vs Distance along Acceptor for Tritonal

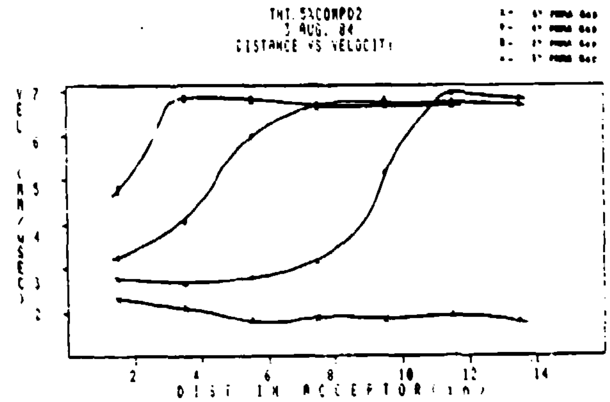

Fig. 18. Velocity vs Distance along Acceptor for TNT/5%-Wax

illustrates the characteristics of the results of the piezoelectric pin data. Figure 18 shows the plot of velocity versus distance along the acceptor for this series of shots. The first shot was set-up with a gap of 6-in. PMMA between the donor and acceptor charges corresponding to 14 kbar input shock from calculations. The shock enters the acceptor at 2.5 mm/us but quickly decelerates producing a "no-go". A 5-in. PMMA gap (18 kbar) is a "go" for the acceptor though detonation does not occur until after a run of 11.1-in. The shock velocity remains under 3 mm/us for 8-in. before beginning to rise to the detonation velocity. A 4-in. PMMA gap (24 kbar) results in an even shorter run to detonation (6.3-in.) and a 2-in. PMMA gap (42 kbar) produces an almost immediate rise to detonation in only 3.5-in. Witness plate markings for all of these shots confirm measurements of distance of run to detonation. The pin data also infers a constant detonation velocity for the acceptor. An analysis of thirteen data points from all shots where the acceptor is detonating reveals a mean detonation velocity of 6.75 mm/us with a standard deviation of 0.09 mm/us.

A series of shots with TNT/35%-NQ/5%-wax acceptors reveal additional utility of the super gap test. As shown in Fig. 19, two shots with a 4-in. PMMA gap and a 3-in. PMMA gap both resulted in a "no-go". A shot with 2-in. PMMA and no endplates (80 kbar) defined a detonation velocity at 7.42 mm/us with a standard deviation of 0.05 mm/us. A 2-in. PMMA shot (with endplates--42 kbar) revealed an interesting result. The velocity along the length of the acceptor plateaus at 5.9 mm/us before continuing to 7.42 mm/us. The charges were cast in acceptor casings in a vertical position

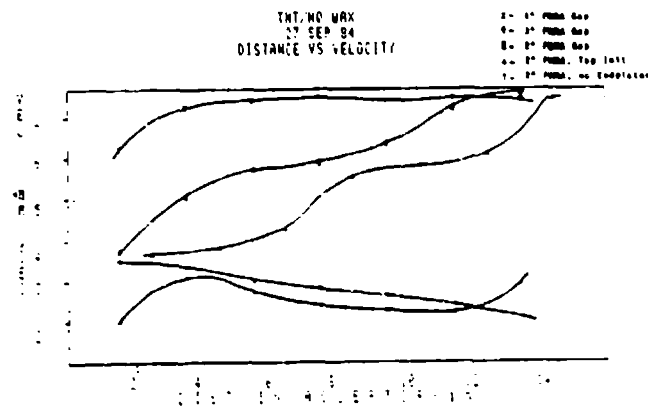

Fig. 19. Velocity vs Distance along Acceptor for TNT/35%-NQ/5%-Wax

and shots were conducted by shocking the bottom end of the charge. For the TNT/NQ/wax charges, however, questions were raised concerning the uniformity of the mixing of TNT and NQ in the charge. A top initiated shot was also completed with 2-in. PMMA. This shot revealed a similar plateau in velocity but 2-in. later in the acceptor. The plateau effect was concluded to be caused by the initiation of NQ (detonation velocity of 6.9 mm/us) before the TNT (detonation velocity of 8.0 mm/us). Since heavier NQ (density, 1.69 gm/cm^3) settled in the TNT (density, 1.62 gm/cm^3) in the casting, the top of the charges contained less concentration of NQ and thus the lower plateau of the shock velocity must occur further along the acceptor in a top initiated charge. The super gap test results support these conclusions. However, no chemical analysis of this series of charges is available which would provide conclusive evidence.

RESULTS AND CONCLUSIONS

The results of the super gap test can be compared to published NOL large scale gap test data[4]. Such a comparison concludes that detonation occurs at lower pressures in the super gap test than in the NOL test. Tritonal detonates in the NOL test at 25-50 kbar and in the super gap test at 15 kbar. Composition-B detonates in the NOL test at 18-20 kbar and in the super gap test at 12 kbar. The difference in pressure again relates to the relative size of these tests and the resulting difference in pressure-time response. The super gap test produces long duration pressure pulses such as occur in large munitions. The longer pressure pulse duration in the super gap test results in lower "go, no-go" pressures than those determined in the NOL gap test.

The super gap test can provide a more comparative study of the sensitivity of high explosives in large unitary weapons. The relatively small scale of the NOL gap test results in an unclear correlation to large scale events. The questions surrounding the sympathetic detonation of large munitions can only be answered with a properly scaled test. The super gap test provides such a scale for proper pressure-time correlation to large weapons.

Baseline tests of the super gap test were accomplished on tritonal and composition-B acceptors. The test was extensively used in the evaluation of EAK mixtures for use as an insensitive high explosive. The super gap test is currently being utilized in investigations of insensitive high explosive mixtures of TNT and wax. The super gap test promises to provide a comparative investigation of high explosive as it relates to utilization in large unitary weapons[5].

ACKNOWLEDGMENTS

The authors wish to express their appreciation to the personnel of the Air Force Armament Laboratory's High Explosive Research and Development group who formulated and fabricated all of the energetic materials used in these experiments. Special thanks is extended to Mr. B. G. Craig who has since retired. His participation in the design phase of the super gap test was invaluable.

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